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ANALYTICAL STUDIES OF TURBULENT FLOW FIELDS(U)  
WISCONSIN UNIV-MADISON DEPT OF MATHEMATICS G L MELLOR  
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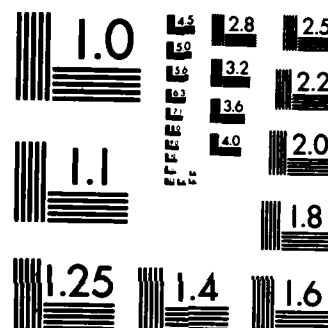
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <b>This constitutes our final report under AFOSR Grant 79-0018 of studies related to second moment turbulence modeling. The emphasis has been on separating flows using a fully elliptical numerical algorithm. A new closure in two-point correlation space has been investigated; it is used to account for several properties of decaying isotropic turbulence.</b>		

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Final Report

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ANALYTICAL STUDIES

of

TURBULENT FLOW FIELDS

AFOSR ██████████-79-0018

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## STATEMENT OF WORK

### Separated Flow

Most of the grant was expended in support of the Ph.D. thesis "Numerical Solution of Incompressible Planar Turbulent Separated Flow" by Dr. M. C. Celenligil. Dr. Celenligil was awarded the Ph.D. degree in June 1982. The ABSTRACT of his thesis is as follows:

In this study, turbulent boundary layer separation is studied using the turbulence closure model suggested by Mellor and Yamada (1974, 1977). The governing transport equations for mean vorticity, for all non-zero components of the Reynolds stress tensor and for the turbulent length scale, are solved numerically for two-dimensional (planar), incompressible turbulent flows. Poisson's equation is then solved numerically to obtain the mean stream function and, then, the mean velocity fields.

The first two problems of the three which are considered, have separated flow configurations. These are: separated flow on a flat surface, and separated channel flow behind a backward-facing step.

In the problem of separation on a flat surface a stationary separated flow structure is obtained. The pressure gradient is the most important factor in the determination of the overall flow structure and the location of the separation point. The various boundary conditions for the turbulence intensities at the wall show almost no effect on the results. However, the results improve when the shear stress at the wall is determined using a "law-of-the wall" layer model modified to account for wall shear stress gradient. Also, in the region close to the exit, the results are affected by the exit boundary conditions. The results support the hypothesis that the reverse flow in the separation region is not supplied by the small mean backflow far downstream.

In the problem of separated flow behind a backward-facing step, unsteady vortex shedding is observed and the flow eventually becomes nearly cyclic in time. In order to make comparison with the experimental data, the computational results are averaged over an integral number of cycles. The effect of unsteadiness is found to be important only in the recirculation region downstream of separation. Also the shear stress starts decreasing in the middle of the recirculation region, well upstream of the reattachment point. Downstream of reattachment, the return of the shear layer into the fully developed channel flow configuration is very slow.

In the third problem, turbulent free shear layer with streamwise curvature is studied. In this problem separation was prevented by boundary layer suction. In our computations a stationary flow configuration is obtained. The flow is like a jet near the walls. Fluid is entrained by the jet and enters the computational domain through the top open boundary. The results are found to be extremely sensitive to the open boundary conditions.

The computational results are plotted and compared both with experimental data and with the results obtained by other computer groups using different turbulence models.

Dr. Celenligil and Dr. Mellor were coauthors in the Proceedings of the 1980-81 AFOSR-HTTM-Stanford Conference on Complex Turbulent Flows. In addition, they are coauthors of the paper "Numerical Solution of Two-Dimensional Turbulent Separated Flows Using a Reynolds Stress Closure Model." The paper is provisionally accepted for publication in the Journal of Fluids Engineering subject to minor revision. The ABSTRACT of that paper is as follows:

Turbulent boundary layer separation is studied using the turbulence closure model suggested by Mellor and Yamada. An explicit central finite-differencing scheme is used to solve the governing transport equations. Three flow problems are considered: separation on a flat surface, separation and reattachment over a backward-facing step, and turbulent free shear layer with streamwise curvature. In the problem of separation behind a backward-facing step, nearly cyclic vortex shedding is obtained whereas the other two problems are stationary. The computed results for both mean and turbulence quantities are in fairly good agreement with experimental data.

Mr. Brian Smith was supported by the grant in his first year of graduate studies. He has made considerable progress in studying the sharp corner separation problem and has successfully sustained the Ph.D. General Examination.

### Two-Point Turbulence Closure

The grant supported Prof. Mellor's work on two-point turbulence closure. He worked with Dr. J.A. Domaradzki (supported by NOAA). A Paper "A Simple Turbulence Closure Hypothesis for the Triple Velocity Correlation Function in Homogeneous Isotropic Turbulence" has been accepted for publication by the Journal of Fluid Mechanics. The ABSTRACT is as follows:

A simple, two-point closure scheme for homogeneous, axisymmetric turbulence is developed. For the isotropic case it is essentially an eddy viscosity assumption in real space for the Kármán-Howarth equation. The eddy viscosity function for large internal Reynolds numbers is derived from Kolmogoroff's 1941 theory. For moderate Reynolds numbers of the order  $10^2$ , approximately the same expression for the eddy viscosity function is determined from experimental data. The resulting closed equation for the double correlation function is solved numerically for both large and moderate Reynolds numbers and the results are compared with experimental data. Self-similar solutions of the basic equation predict turbulent energy decay inversely proportional to time. It is shown that the departure from this "initial period decay law" observed in laboratory data is due to the behaviour of grid produced correlation functions for large separation distances.

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